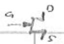
Fecha: ______________________

Asunto: ______________________ Página: ______________________

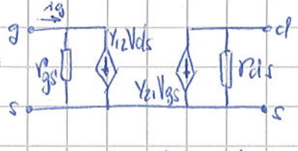
JFET (TIPO N) 

SAT: $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$, $V_{GS} < 0$ $V_{GS} > V_P$ $V_{DS} \geq V_{GS} - V_P$ $V_{DS} < 0$ $I_{DSS} > I_{DQ}$

$V_{GSQ} = V_P\left(1 - \sqrt{\frac{I_{DQ}}{I_{DSS}}}\right)$

SIGNOS: JFET N / NMOS => $I_D > 0$ => $I_{DSS} > 0$, $V_{GS} < 0$ => $V_P < 0$ $I_G \simeq 0$

PEQUEÑA SEÑAL: (EN SAT)



$i_g = Y_{is} \cdot V_{gs} + Y_{rs} \cdot V_{ds}$ $Y_{is} = \frac{\partial i_G}{\partial V_{GS}}\Big|_Q$ $Y_{rs} = \frac{\partial i_G}{\partial V_{DS}}\Big|_Q$ $Y_{fs} = \frac{\partial i_D}{\partial V_{GS}}\Big|_Q$ $Y_{os} = \frac{\partial i_D}{\partial V_{DS}}\Big|_Q$

$i_d = Y_{fs} \cdot V_{gs} + Y_{os} \cdot V_{ds}$

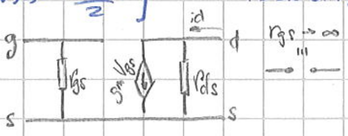
$Y_{12} \cdot V_{ds} = Y_{rs} V_{ds}$ $Y_{21} \cdot V_{gs} = Y_{fs} \cdot V_{gs} = g_m \cdot V_{gs}$ $r_{gs} = \frac{1}{Y_{11}} = \frac{1}{Y_{is}}$ $r_{ds} = \frac{1}{Y_{22}} = \frac{1}{Y_{os}}$

TRANSCONDUCTANCIA: $g_m = Y_{fs} = g_{mo}\left(1 - \frac{V_{GSQ}}{V_P}\right)$ $g_{mo} = -\frac{2 I_{DSS}}{V_P}$ $g_m = g_{mo}\sqrt{\frac{I_{DQ}}{I_{DSS}}}$ $g_m = \frac{\partial i_D}{\partial V_{GS}}\Big|_Q$

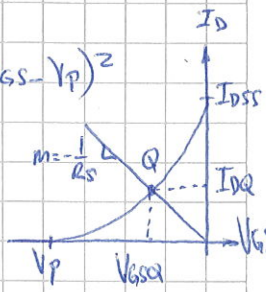
NMOS

· I_D EN Ω ; $I_D = \mu_n \cdot C_o \cdot \frac{W}{L}\left[(V_{GS} - V_P)V_{DSS} - \frac{V_{DS}^2}{2}\right]$ · I_D EN SAT: $I_D = \frac{\mu_n \cdot C_{ox}}{2} \cdot \frac{W}{L}(V_{GS} - V_P)^2$

$V_{DS} \leq V_{GS} - V_P$

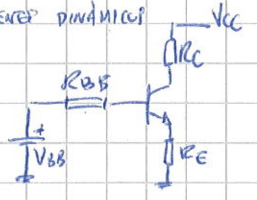


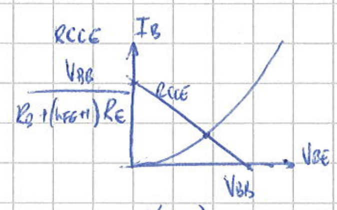
RESISTENCIA DE CANAL: $I_D = V_{DS}/R_{CANAL}$



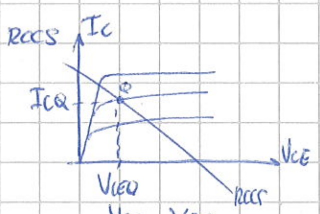
FET Y MOS VACIAMIENTO

MÁRGENES DINÁMICOS

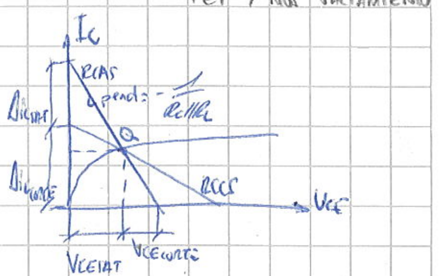




$I_B = \frac{V_{BB} - V_{BE}}{R_B + (h_{FE}+1)R_E}$



$I_C = \frac{V_{CC} - V_{CE}}{R_C + R_E}$



$\Delta V_{CESAT} = V_{CEQ} - V_{CESAT}$ $\Delta V_{CECORTE} = \frac{I_{CQ}}{|\text{PENDIENTE}_{RCAS}|}$ (| | = VALOR ABSOLUTO) $\Delta I_{CSAT} = (V_{CEQ} - V_{CESAT}) \cdot |\text{pend.}_{RCAS}|$ $\Delta I_{CCORTE} = I_{CQ}$

MARGEN DINÁMICO TENSIÓN: $\Delta V_{CE} = \Delta V_{CESAT} + \Delta V_{CECORTE}$ MES TENSIÓN: $MES(V_{CE}) = 2 \times \min(\Delta V_{CESAT}, \Delta V_{CECORTE})$

" " CORRIENTE: $\Delta I_C = \Delta V_{CE}/R_L$ MES CORRIENTE: $MES(I_C) = MES(V_{CE})/R_L$

MES ÓPTIMA: 1/ $\Delta V_{CESAT} = \Delta V_{CECORTE}$ → $\frac{MES}{2} = V_{CEQ}^{?} - V_{CESAT} = \frac{I_{CQ}^{?}}{|\text{pend}|}$ 2/ $Q \in RCCS \rightarrow V_{CC} = V_{CEQ}^{?} + I_{EQ} \cdot R_E$ (I_{CQ}?)

(CÁLCULO DE R1 Y R2 *)

EL DISEÑO Q DEBE CUMPLIR: $V_{CEQ} > V_{CESAT}$ => ACTIVA.

* $V_{BB} = V_{CC}\frac{R_1}{R_1+R_2}$ $R_{BB} = R_1 // R_2$ $R_1 = \frac{V_{BB}}{V_{CC} - V_{BB}} R_2$ $R_2 = \frac{V_{CC} \cdot R_{BB}}{V_{BB}}$

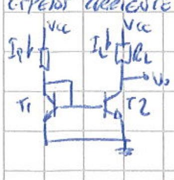
DARLINGTON

$h_{FE} = \frac{I_C}{I_B} = h_{FE1} \cdot h_{FE2}$ $V_{BE} = 1'4V$ $V_{CESAT} = V_{BE2_{ACT}} + V_{CE1_{SAT}} = 0'9V$ → T2 NUNCA EN SAT.

($V_{BE2_{ACT}} = 0'7$, $V_{CE1_{SAT}} = 0'2$)

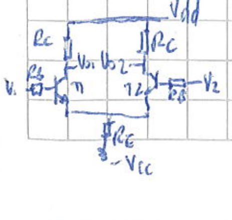
$V_{CE} = V_{CE1} + V_{BE2}$

ESPEJO CORRIENTE



T1 SIEMPRE ACT. $V_{CE} = V_{BE} = 0'7V$ $I_L = \frac{I_P}{1 + \frac{2}{h_{FE}}}$ $I_P = \frac{V_{RP}}{R_P} = \frac{V_{CC} - V_{BE_{ACT}}}{R_P}$ ($V_{BE_{ACT}} = 0'7$) $I_{C_1} = I_{C_2} = I_{ES1} e^{V_{BE1}/V_T}$

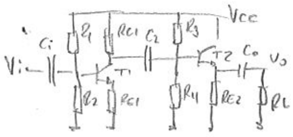
T1 ≡ T2



$V_{o1} = Ad_1 V_d + Ac_1 V_c$ $Ac_1 = \frac{-h_{fe} R_C}{R_B + h_{ie} + 2R_E(h_{fe}+1)} = Ac_2$; $Ad_1 = -Ad_2 = -\frac{h_{fe} R_C}{2(R_B + h_{ie})}$

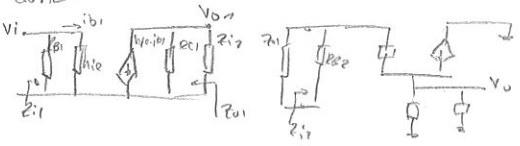
$V_{o2} = Ad_2 V_d + Ac_2 V_c$

$CMRR = \left|\frac{Ad}{Ac}\right|$



→

En AC :



$1mm^2 = 0'01 cm^2$

$1mm = 0'1 cm$

Fecha:

Asunto: Página:

$q_e = 1'6 \cdot 10^{-19} C$

• ESTAT SÒLID

SC EXTRÍNSEC ($N > P$) e^-, h^+/FORATS; TIPUS N; [ ] = cm^{-3}; $T: 273°K$

LLEI ACCIÓ DE MASSES: 1. $np = n_i^2(T)$ (TEMPERATURA)

CONDUCTIVITAT: 2. $\sigma = q_e(\mu_p p + \mu_n \cdot n)$ ($cm^2/V \cdot s$); DENSITAT CORRENT $(\Omega cm)^{-1}$

[ ] IMPURESES (DONADORES, ACCEPTORES) cm^{-3}

3. $N_d + p = N_a + n$ — LLEI NEUTRALITAT CÀRREGA (ACCEPTOR, DONADOR)

$\rho = \frac{1}{\sigma}$ Ωcm

RESISTÈNCIA Ω: $R = \rho \cdot \frac{\ell}{S}$

SC INTRÍNSEC

[ ] e^-, h^+: $n = p = n_i(T)$ cm^{-3}

$\sigma = q_e \cdot n_i (\mu_p + \mu_n)$ — MOVILITAT h^+, e^-; CONDUCTIVITAT $(\Omega cm)^{-1}$

$R = \frac{1}{\sigma} \cdot \frac{\ell}{S}$ (cm; S - cm^2)

$dR = \rho(x) \cdot \frac{dx}{A}$ (A - secció)

1,3: $n^2 - (N_d - N_a)n - n_i^2 = 0$

DOPAT DONADORS (e^-): • $n \gg p \rightarrow n \simeq N_d$; $N_a = 0$

SI MOVILITATS MATEIX ORDRE: $\sigma = q_e \mu_n N_d$; $\sigma = \frac{1}{R} \cdot \frac{\ell}{S}$

1,2: $n^2 - \frac{\sigma}{q_e \mu_n} n + \frac{\mu_p}{\mu_n} n_i^2 = 0$, $n \simeq n_i$

DOPAT ACCEPTORS (h^+): • $p \gg n \rightarrow p \simeq N_a$

$\sigma = q_e \cdot \mu_p \cdot N_a \leftarrow n = \frac{n_i^2(T)}{p}$, $n \ll p$

A. $J_{dn} = q_e D_n \frac{dn(x)}{dx}$ — CORRENT DIFUSIÓ e^- ($V_T \cdot \mu_n$)

B. $J_{an} = q_e \mu_n n(x) \cdot E(x)$ — CAMP ELÈCTRIC (σ; $p(x)$)

$J_{dp} = -q_e D_p \frac{dp(x)}{dx}$ — DENSITAT CORRENT DIFUSIÓ h^+

$J_{an} + J_{dn} = 0$ ($J_T = 0$)

$J_{an} = -J_{dn}$ × EQUILIBRI × EN ABSÈNCIA DE CAMP ELÈCTRIC EXTERIOR

A,B: $E(x) = -V_T \cdot \frac{1}{n(x)} \cdot \frac{dn(x)}{dx}$

$I = J_T \cdot S$

$J_T = J_{an} + J_{dn} + J_{ap} + J_{dp}$

si $n_1 < n_2 \rightarrow \ln \frac{n_1}{n_2} < 0 \rightarrow V_2 > V_1$

$V_1 - V_2 = V_T \ln \frac{n_1}{n_2}$ — DIF. DE POTENCIAL

POT. EQUIVALENT TEMP.; CONSTANT DIFUSIÓ: $V_T = \frac{D_n}{\mu_n} = \frac{K \cdot T}{q_e}$ — RELACIÓ EINSTEIN

$W_p \cdot N_a = W_n \cdot N_d$

$W_0 = \sqrt{\frac{2\varepsilon}{q_e}\left(\frac{1}{N_a} + \frac{1}{N_d}\right) \cdot (V_0 - V)}$ (µm) — AMPLADA ZCE; $\varepsilon = \varepsilon_r \cdot \varepsilon_0$ F/cm

TENSIÓ INV. POLARITZACIÓ → UNIÓ P-N ABRUPTA POL.

$\rightarrow V_0 = V_T \ln \frac{N_a \cdot N_d}{n_i^2}$ (25mV) — POT. CONTACTE

$\rightarrow W_0 = W_n + W_p$ — LONGITUDS DE LES PARTS DE ZCE (W_n, W_p)

$W_p = X_p$; $W_n = X_n$

AMPLADA ZCE: $W_{n_p} = \frac{N_{a,d}}{N_a + N_d} \cdot W_0$?

$N_a < N_d$; $X_p < X_n \rightarrow W_0 = (W_n)$

N_D si $N_A \gg N_D$

$J = \sigma \cdot E$ — LLEI D'OHM

$E_{max} = -\frac{2V_0}{W_0}$ — CAMP E MÀXIM - ZONA SENSE POLARITZAR -

$V = RI$

$E = -\frac{dV}{dx} \rightarrow \int_0^x dV = -\int_0^x E dx \rightarrow V(x) - V(0) = -\int_0^x E dx$

$|E_m| = \sqrt{\frac{2q_e}{\varepsilon} \cdot \frac{1}{\frac{1}{N_a} + \frac{1}{N_d}} (V_0 - V)}$ — SENSE POLARITZAR

ÀREA CONTACTE

A $I_S = q_e A n_i^2 \left(\frac{D_p}{L_p} \cdot \frac{1}{N_d} + \frac{D_n}{L_n} \cdot \frac{1}{N_a}\right)$ — CORRENT INVERS SATURACIÓ

$p_n = \frac{n_i^2}{N_d}$; $n_p = \frac{n_i^2}{N_a}$

$L_{pn} = \sqrt{D_{pn} \cdot \tau_{pn}}$ (cm) — ZONES NEUTRES; LONGITUD DE DIFUSIÓ

$\frac{D_p}{L_p} = \sqrt{\frac{D_p}{\tau_p}}$

$L_{pn} = X_{pn} \cdot W_{pn}$ (µm)

$R_p = \frac{1}{\sigma} \cdot \frac{L_p}{A}$

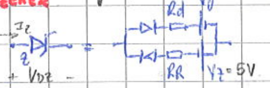
F $C_T = A \cdot \frac{\varepsilon}{W}$ — CAPACITAT TRANSICIÓ

• DIODE

ON $\begin{cases} i_d > 0 \\ V_d = 0 \end{cases}$ IDEAL ($V_T = 0$, $R_f = 0$)

OFF $\begin{cases} i_d = 0 \\ V_d < 0 \end{cases}$

• ZENER



INV $\begin{cases} i_d < 0 \\ V_d = -5V \; (-V_Z) \end{cases}$

OFF $\begin{cases} i_d = 0 \\ -5 < V_d < 0 \end{cases}$

1. DC: $\frac{I_{DQ}}{V_{DQ}} \rightarrow r_d$; capacitor → c.a.

$I_{DQ} = I_S\left(e^{\frac{V_{DQ}}{\eta V_T}} - 1\right)$

$r_d = \frac{\eta \cdot V_T}{I_{DQ}} = \frac{1}{\frac{di_D}{dv_D}\big|_Q} = \frac{1}{V_{DQ}} \cdot \frac{1}{m}$

$\eta = 1$ ó 1'5; $V_T = 25mV$

2. AC: i_d v_d

$\begin{cases} i_D = I_{DQ} + i_d \text{ (mA)} \\ V_D = V_{DQ} + v_d \text{ (V)} \end{cases}$

$r_d = \frac{V_d}{i_d}$

$|X_C| = \frac{1}{\omega C}$

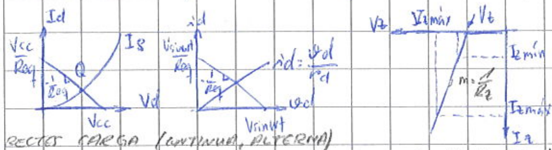
ZENER RUPTURA:

$V_Z = I_Z \cdot R_Z + V_Z$

$V_{Z} > 0$, $i_Z = I_S e^{\frac{V_Z}{\eta V_T}}$

NO COND: $-V_Z \leq V_Z \leq 0$

INVERSA: $V_Z < -V_Z$



$I_{Zmax} = \frac{V_{imax} - V_{Zmax}}{R_{max}} - I_{L\,min}$

$I_{Zmax} = \frac{V_{imax} - V_Z}{R} - \frac{V_Z}{R_{L\,max}}$ ($I_{L\,min}$)

$I_{Zmin} = \frac{V_{imin} - V_{Zmin}}{R_{max}} - \frac{V_{Zmin}}{R_{L\,min}}$

PENDIENTE: $\frac{1}{R} = \frac{\Delta I}{\Delta V}$

RECTES CARGA (CONTINUA, ALTERNA)

PEND: $\frac{1}{R_Z} = \frac{I_{Zmax} - I_{Zmin}}{V_{Zmax} - V_{Zmin}}$ — RESIST. VISTA X DIODO EN AC ó EN DC; REND AC ≠ REND DC

TENSIÓ ENTRADA: $V_i = V_{ef} \sqrt{2} \sin \omega t$ ($V_{max} = V_{pic}$)

VALOR MITJÀ SENYAL PERIÒDIC (MONTAT): $I_{dc} = \frac{1}{T}\int_0^T I_{max} \sin(\omega t)\, d\omega t$ (PERÍODE; I_{pic})

VALOR EFICAÇ: $I_{ef} = \sqrt{\frac{1}{T}\int_0^T i_D^2\, d\omega t} = \frac{I_{max}}{\sqrt{2}}$; $i = I_{max} \cdot \sin(\omega t)$

POTÈNCIA MITJA: $P = \frac{1}{2\pi} \int V_d \cdot i\, d\omega t$ (ω) — DIODE; FUNT - V_i; V_T

$\begin{cases} V_i = V_{max} \sin \omega t \\ i = I_{max} \sin \omega t \end{cases}$

$P_{max} = V \cdot I_{max}$

CORRENT DIODE MÀXIMA: $I_{Dpic} \simeq I_m = V_m \sqrt{\frac{1}{R_L^2} + C^2 \omega^2}$

POTÈNCIA: $P_{MEDIA} = V_T \cdot I_D$ (DIODE)

I MITJA — MITJA ONA: $I_D = I_{ODC} = \frac{V_{ODC}}{R_L}$ — COND —

ONA COMPLETA: $I_D = \frac{I_{ODC}}{2} = \frac{V_{ODC}}{2R_L}$ (GRAETZ)

$V_{INV} = 2V_{im}$ (V_i (GRAETZ)) — TENSIÓ INVERSA MÀX

MITJA ONA: $I_{DC} = \frac{I_{max}}{\pi}$

$I_{ef} = \frac{I_{max}}{2}$

$\frac{V_{max}}{\sqrt{2}} = V_{ef}$

$P = \frac{V_{max} \cdot I_{max}}{4}$

$V_{OEF} = \frac{V_M}{2}$ — MITJA ONA

ONA COMPLETA: $V_{OEF} = \frac{V_m}{\sqrt{2}}$

ONA COMPLETA: $V_{oDC} = \frac{2V_{om}}{\pi}$ (V_o MITJA)

$V_{om} \cdot I_{om} \cdot R_L$: $R_L = \frac{V_{odc}}{I_{odc}}$

$I_{oef} = \frac{I_{om}}{\sqrt{2}}$ (MÀX)

$V_{ef} = \frac{V_{om}}{\sqrt{2}}$

$V_o = |V_i| = V_{im} |\sin \omega t|$

$\omega = 2\pi \nu$; $T = \frac{2\pi}{\omega}$; $T = \frac{1}{\nu}$

ARRISSATMENT DE TENSIÓ (MITJA ONA): $\Delta V_o = \frac{V_m}{2 R_L C \nu} = \frac{I_{odc} V_m}{V_{odc} \cdot C \cdot \nu} \cdot \frac{1}{2}$ (ONA COMPLETA - 2·)

$V_{odc} = V_m - \frac{\Delta V_o}{2}$ — VALOR MITJÀ TENSIÓ SORTIDA; TENSIÓ PIC (SORTIDA)

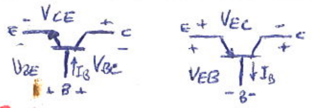
$\tau = R_L \cdot C$

$\varphi = \arctg(R_L \cdot C \cdot \omega) \simeq 90°$

$\frac{dV_o(t)}{dt} = \frac{V_{co}}{R_L \cdot C}$

FILTRE AMB CONDENSADOR

DIODE OFF → A —▷|— B $V_A < V_B$



- BJT

$V_{CE} = V_{CB} + V_{BE}$ $I_{CQ} = \beta \cdot I_{BQ}$ $I_{EQ} = (\beta+1) I_{BQ}$

$I_E = I_B + I_C$ $I_{CQ} = \alpha \cdot I_{EQ}$ $I_{BQ} = (1-\alpha) I_{EQ}$

1) $I_{BQ} > 0 \rightarrow$ ACT. ó SAT. ← 1) $I_{EQ} > 0$

2) $V_{CEQ} > V_{CESAT} \rightarrow$ ACT.

- ZONAS FUNCIONAMIENTO -

CORTE: $V_{BB} < V_{BEACT} = 0'7V$ $I_{BQ} < 0$

SAT: $V_{CESAT} = 0'2V$, $I_C < \beta \cdot I_B$, $I_{BQ} > 0$

ACT: $V_{CEQ} > V_{CESAT}$ $I_{BQ} > 0$

- BJT -

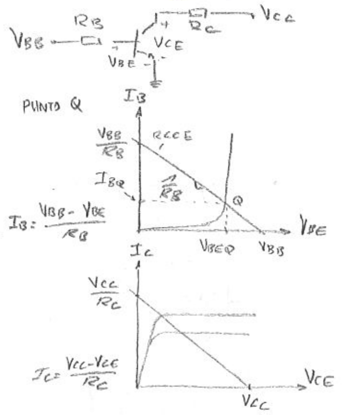
CORTE: $I_B = 0$ $I_C = 0$ $V_{BE} < V_{BEACT}$

ACT: $V_{BE} = V_{BEACT}$ $I_C = h_{FE} \cdot I_B$ $I_B > 0$ $V_{CE} > V_{CESAT}$

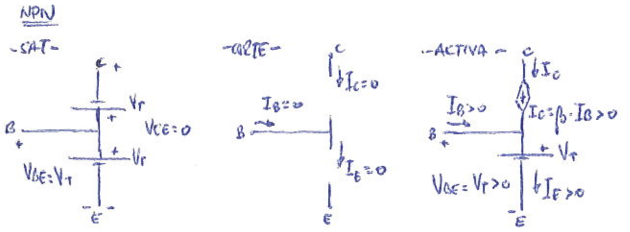
SAT: $V_{BE} = V_{BEACT}$ $I_C = I_{CSAT}$ $V_{CE} = V_{CESAT}$ $I_B > 0$

→ $I_E = I_B + I_C$ $I_{CSAT} < h_{FE} \cdot I_B$ ($= I_{CACT}$) $I_{BSAT} > I_{BACT}$

PUNTO Q BJT: i_B V_{BE} (RCE) ↓ i_C V_{CE} (RCS)



NPN



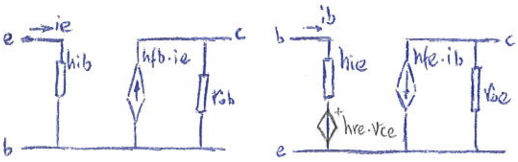
PNP

V_{BE}: $V_r = -0'5$ V_{CE}: SAT = $-0'2$

$V_{BE} = -V_{EB}$ ACT = $-0'7$

$V_{EB} = V_E - V_B$ SAT = $-0'8$

TALL = 0



$h_{ie} = \frac{\eta V_T}{I_{EQ}}$ $\eta := 1$ $V_T = 25mV$

$h_{ie} = \frac{V_T}{I_{BQ}}$ $h_{fb} = \alpha$ $h_{fe} = \beta$ $r_{oe} = \frac{1}{h_{oe}}$

$h_{ib} = \frac{h_{ie}}{h_{ie}+1}$ (Ω) $h_{fb} = \frac{h_{fe}}{h_{fe}+1}$ $h_{ob} = \frac{h_{oe}}{h_{fe}+1}$ (Ω^{-1}) $r_{ob} = \frac{1}{h_{ob}}$ (Ω)

$\begin{cases} v_{be} = h_{ie} \cdot i_b + h_{re} \cdot v_{ce} \\ i_c = h_{fe} \cdot i_b + h_{oe} \cdot v_{ce} \end{cases}$ $h_{ie} = \frac{\partial V_{BE}}{\partial i_B}\Big|_Q$ $h_{re} = \frac{\partial V_{BE}}{\partial V_{CE}}\Big|_Q$ $h_{fe} = \frac{\partial i_C}{\partial i_B}\Big|_Q$ $h_{oe} = \frac{\partial i_C}{\partial V_{CE}}\Big|_Q$

$h_{ie} = \frac{v_{be}}{i_b}\Big|_{v_{ce}=0}$

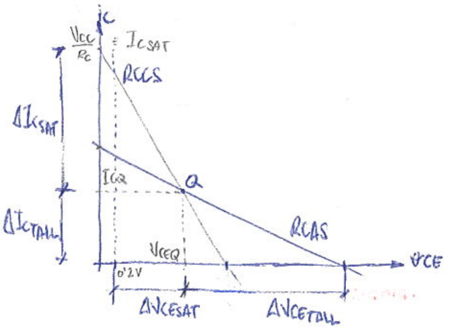
$A_V = \frac{V_o}{V_i}$ $A_i = \frac{i_o}{i_i}$ $A_i = A_V \cdot \frac{Z_i}{R_L}$ $Z_i = \frac{V_i}{i_i}$ $Z_o = \frac{V_o}{i_o}$

$A_V = \frac{\partial V_o}{\partial V_i}$

RCC − $I_C(V_{CE})$ (RCCS)

RCCE − $I_B(V_{BE})$

RCA − $i_c(v_{ce})$ RCAS → $\begin{cases} v_{CE} = V_{CEQ} + v_{ce} \\ i_C = I_{CQ} + i_c \end{cases}$ $i_b(v_{be})$ RCAE → $\begin{cases} v_{BE} = V_{BEQ} + v_{be} \\ i_B = I_{BQ} + i_b \end{cases}$



MARGES DINÀMICS TENSIÓ

* $\Delta V_{CETALL} = V_{CETALL} - V_{CEQ}$ $\Delta V_{CESAT} = V_{CEQ} - V_{CESAT}$ $V_{CETALL} = v_{CE}\big|_{i_C=0}$

MARGES DINÀMICS CORRENT

$\Delta I_{CTALL} = I_{CQ} - I_{CTALL}$ (= 0) * $\Delta I_{CSAT} = I_{CSAT} - I_{CQ}$ $I_{CTALL} = 0$ $I_{CSAT} = i_C\big|_{v_{CE}=V_{CEQ}}$

* $\Delta V_{CETALL} = \frac{I_{CQ}}{|\text{PEND RCAS}|} = I_{CQ} \cdot (R_C \| R_L)$

$\Delta I_{CSAT} = (V_{CEQ} - V_{CESAT}) \cdot |\text{PEND RCAS}|$

MAX. SENYAL (MES)

$\Delta V_i = \frac{\Delta V_o}{A_V}$ MES(V_{CE}) (ΔV_{CE}) $= 2 \times \min(\Delta V_{CESAT}, \Delta V_{CETALL})$ MES(i_C) (Δi_C) $= \frac{MES(V_{CE})}{R_L}$

MES → $\begin{cases} \Delta i_C = \Delta I_{CSAT} + \Delta I_{CTALL} \text{ ó } \Delta i_C = \frac{\Delta V_{CE}}{R_L} \\ \Delta V_{CE} = \Delta V_{CESAT} + \Delta V_{CETALL} \end{cases}$

MES ÓPTIMA: (MÁXIMA OSCILACIÓN SIN DISTORSIÓN)

COND. 1) $\Delta V_{CESAT} = \Delta V_{CECORTE}$ → $V_{CEQ}? - V_{CESAT} = \frac{I_{CQ}?}{|\text{pend. RCAS}|}$

COND. 2) $Q \in RCCS$ → $V_{CC} = V_{CEQ}? + I_{EQ}? \cdot R_E$ ($I_{CQ} \approx I_{EQ}$)

I_{CQ}, V_{CEQ}? EL NUEVO Q DEBE CUMPLIR: $V_{CEQ} > V_{CESAT}$ → ACT.

CÁLCULO DE R1 y R2: $V_{BB} = V_{CC} \frac{R_1}{R_1+R_2}$ $R_{BB} = R_1 \| R_2$ $R_1 = \frac{V_{BB}}{V_{CC} - V_{BB}} R_2$ $R_2 = \frac{V_{CC} \cdot R_{BB}}{V_{BB}}$

CRITERI: $R_{BB} = \frac{1}{10} R_E\, h_{FE}$ $V_{BB} = V_{BEQ} + I_{CQ}\left(\frac{R_{BB}}{h_{FE}} + R_E\right)$ → $I_{CQ} = h_{FE} \cdot I_{BQ} \approx \frac{V_{BB} - V_{BEQ}}{\frac{R_{BB}}{h_{FE}} + R_E}$

SC EXTRÍNSEC (N,P) (IMPURIFICAT) e^- h^+ (FORATS) [ ] = cm^{-3}

$np = n_i^2(T)$ ← TEMPERATURA — LLEI ACCIÓ MASSES

$\sigma = q_e \cdot (\mu_p \cdot p + \mu_n \cdot n)$ — CONDUCTIVITAT ($q_e = 1'6 \cdot 10^{-19}$ C; μ en $cm^2/V \cdot s$) — DENSITAT CORRENT $(\Omega cm)^{-1}$

SC INTRÍNSEC (PURA) [ ] e^-, h^+

$n = p = n_i(T)$ cm^{-3} $\quad \sigma = q_e \cdot n_i \cdot (\mu_p + \mu_n)$ — CONDUCTIVITAT (Ωcm^{-1})

[ ] IMPURESES (DONADORS, ACCEPTADORS) cm^{-3}

$N_d + p = N_a + n$ cm^{-3} — LLEI NEUTRALITAT CÀRREGA (N_a: ACCEPTOR, N_d: DONADOR)

$\rho = \frac{1}{\sigma}$ Ωcm — RESISTIVITAT (σ ← CONDUCTIVITAT)

$R = \rho \frac{l}{S}$ — RESISTÈNCIA Ω

DOPAT DONADORS: $n >> p \rightarrow n \simeq N_D$ $\quad \sigma = q_e \cdot \mu_n \cdot N_D$ $\quad \sigma = \frac{1}{R} \frac{l}{S}$; $N_A = 0$

$J_{dn} = q_e \cdot D_n \cdot \frac{dn(x)}{dx}$ $A \cdot cm^{-2}$ — CORRENT DIFUSIÓ e^-

$J_{an_p} = q_e \cdot \mu_{n_p} \cdot p\, n(x) \cdot E(x)$ — CAMP ELÈCTRIC (σ)

$J_{dp} = -q_e \cdot D_p \cdot \frac{dp(x)}{dx}$ — DENSITAT CORRENT DIFUSIÓ h^+

$J_{an_p} = -J_{dn_p}$ — EQUILIBRI

$V_1 - V_2 = V_T \cdot \ln \frac{n_1}{n_2}$

$V_T = \frac{D_{n_p}}{\mu_{n_p}} = \frac{KT}{q_e}$ — POT. EQUIVALENT TEMP., CONSTANT DIFUSIÓ — RELACIÓ EINSTEIN

$V_0 = V_T \cdot \ln \frac{N_a \cdot N_d}{n_i^2}$ — POTENCIAL DE CONTACTE

$W_0 = \sqrt{\frac{2\mathcal{E}}{q_e}\left(\frac{1}{N_a} + \frac{1}{N_d}\right) \cdot (V_0 - V)}$ μm — AMPLADA ZCE ($\mathcal{E} = \mathcal{E}_r \cdot \mathcal{E}_0$ F/cm; V: TENSIÓ POLARITZACIÓ) → UNIÓ PN ABRUPTA POL.

$W_0 = W_n + W_p$ $\quad W_{n_p} = \frac{N_{a_d}}{N_a + N_d} W_0$

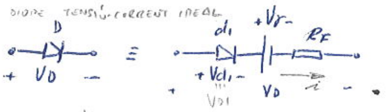
$J = \sigma \cdot E$ — LLEI OHM $\quad E_m = -\frac{2V_0}{W_0}$ — CAMP E MÀXIM $\quad V = RI$ $\quad E = -\frac{dV}{dx}$

$I_S = q_e \cdot A \cdot n_i^2 \left(\frac{D_p}{L_p} \cdot \frac{1}{N_d} + \frac{D_n}{L_n} \cdot \frac{1}{N_a}\right)$ — CORRENT INVERS SATURACIÓ (A: ÀREA)

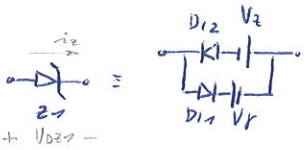
$L_p = \sqrt{D_p \cdot \tau_p}$ cm/s — ZONES NEUTRES (L_n) $\quad L_{p_n} = X_p - W_p$ μm $\quad R_p = \frac{1}{\sigma} \cdot \frac{L_p}{A}$

$C_T = A \cdot \frac{\mathcal{E}}{W}$ F — CAPACITAT TRANSICIÓ

DIODE TENSIÓ-CORRENT IDEAL



IDEALS ($V_\gamma = 0, R_F = 0$) V_{d1}
DON ($i > 0$, $V_{D1} = 0$)
DOFF ($i = 0$, $V_{D1} < 0$)



DZ: ON: $V_{dz} = V_\gamma$, $i > 0$; OFF: $-V_z < V_{DZ} < V_\gamma$, $i = 0$; ON: $V_{dz} = -V_z$, $i < 0$

$V_i = V_{ef} \sqrt{2} \sin \omega t$ ($V_{màx} = V_{ef}\sqrt{2}$) — TENSIÓ ENTRADA

$S_{dc} = \frac{1}{T} \int_0^T s(\alpha)\, d\alpha$ (I, PERÍODE; $\frac{1}{T}\int_0^T I_{màx} \sin \omega t \, d(\omega t)$) — VALOR MITJÀ SENYAL PERIÒDIC

$I_{ef} = \frac{I_{màx}}{\sqrt{2}}$ $\quad V_{ef} = \frac{V_{màx}}{\sqrt{2}}$ $\quad V_{ef} = \frac{V_{o\,pic}}{\sqrt{2}}$

$P = \frac{1}{2\pi} \int_0^{2\pi} V_i \cdot i \, d\alpha$ — POT. MITJA

$P_{màx} = V \cdot I_{màx}$

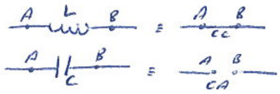
$S_{ef} = \sqrt{\frac{1}{T} \int_0^{2\pi\, T} s^2(\alpha)\, d\alpha}$ — VALOR EFICAÇ (I_{D1}; $i_{D1}^2 \, d(\omega t)$; $i = I_{màx} \cdot \sin \alpha$, $d\omega t$)

$\Delta V_0 = \frac{V_m}{R_L C f} = \frac{I_{odc} \cdot V_m}{V_{odc} \cdot C \cdot f}$ — ARRISSAMENT DE TENSIÓ (R_L: RESISTÈNCIA DE CÀRREGA)

$V_{odc} = V_m - \frac{\Delta V_0}{2}$ — VALOR MITJÀ TENSIÓ SORTIDA (V_m: TENSIÓ PIC/SORTIDA)

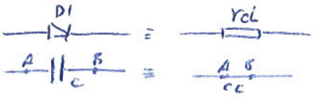
$\left.\frac{di_D}{dv_D}\right|_Q$

1. DC: I_{DQ}, V_{DQ} → r_d



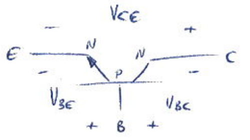
$I_{DQ} = I_S \left(e^{\frac{V_{DQ}}{n V_T}} - 1\right)$ $\quad r_d = \frac{n V_T}{I_{DQ}} = \frac{1}{V_{DQ}} = \frac{1}{m}$

2. AC: i_d, v_d — PETIT SENYAL



$i_D = I_{DQ} + i_d$
$V_D = V_{DQ} + v_d \rightarrow v_d = V_D - V_{DQ}$
$V_d = r_d \cdot i_d$

$I_C = \beta \cdot I_B$
$I_E = (\beta + 1) \cdot I_B$



$V_{BE} > 0$ directa; $V_{BC} < 0$ inversa — ACTIVA ($I_C < I_{C(sat)}$, $V_{CE} < V_{CE(sat)}$)

APROXIMACIÓ LINEAL PER TRAMS: $I = I_S \left(e^{V/V_T} - 1\right)$

PTO Q: (I_B, I_C, V_{BC})

1. $V_{CE} = V_{CC} - I_C R_C$ $\quad V_{CE} = V_{CB} + V_{BE}$ $\quad V_{CE} = V_C - V_E$
2. $I_C = \beta \cdot I_B$ ($h_{FE} = \beta$) $\quad I_E = I_C + I_B$
3. $I_B = \frac{V_{BB} - V_{CE}}{R_B}$

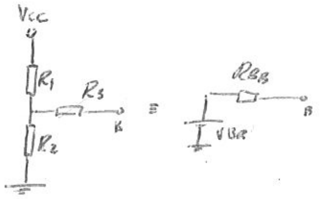
TRT EN ACTIVA: $(V_{BE} = 0'7V)$ $\quad V_{BE} > 0$ DIRECTA, $V_{BC} < 0$ INVERSA.

$I_C = \beta \cdot I_B$
$I_E = (\beta + 1) I_B$

TRT EN SAT: $I_C > I_{C(SAT)}$ $\quad V_{BE} > 0$ DIRECTA, $V_{BC} > 0$ " .

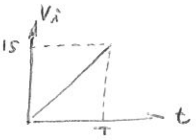
$I_{C(SAT)} = \frac{V_{CC}}{R_C}$

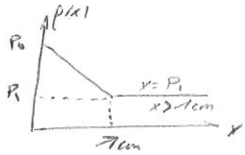
$\beta_1 = \beta_2 = 100 \rightarrow \beta + 1 \simeq \beta \rightarrow I_E \simeq I_C = I_B \cdot \beta$

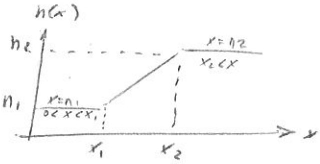


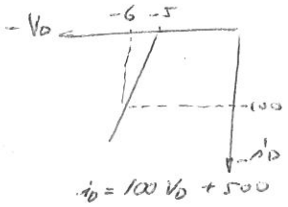
$$R_{BB} = \frac{R_1 R_2}{R_1 + R_2} + R_3$$

$$V_{BB} = R_2 \frac{V_{CC}}{R_1 + R_2}$$









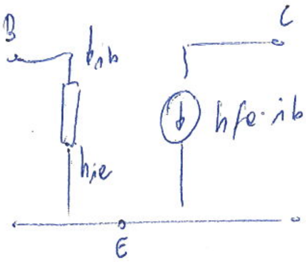
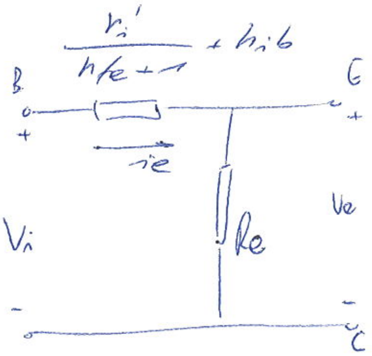
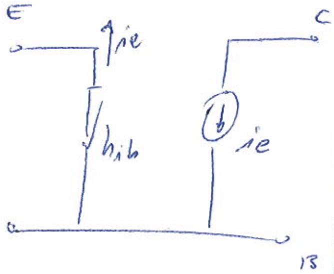
$V_i = \frac{15}{T} t \quad 0 \le t \le T$

$p_0 + (p_1 - p_0)x \quad 0 < x < 1cm$

$\frac{n_2 - n_1}{x_2 - x_1}(x - x_1) + n_1 \quad x_1 \le x \le x_2$

$i_D = 100 V_D + 500 \quad V_D < -5V$

Tabla de parámetros importantes de las tres configuraciones básicas. (BJT)

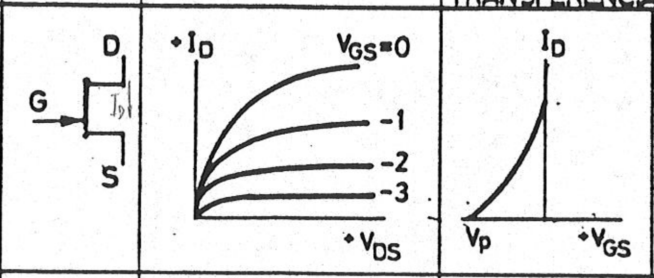
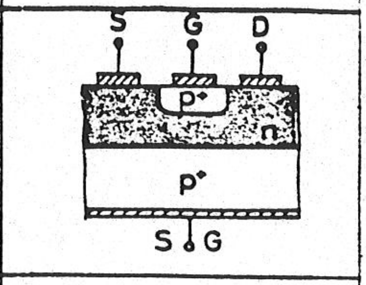
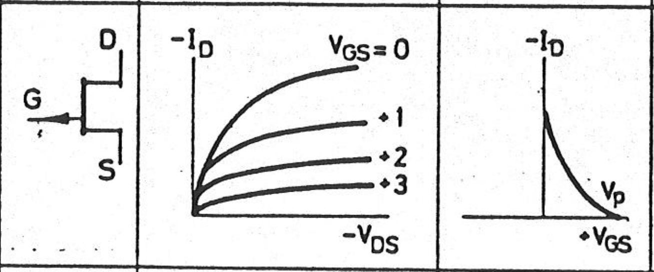
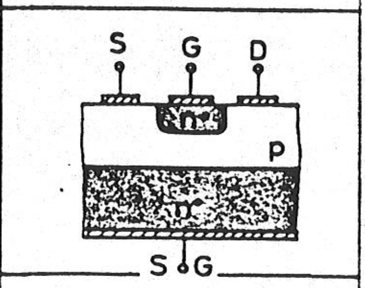
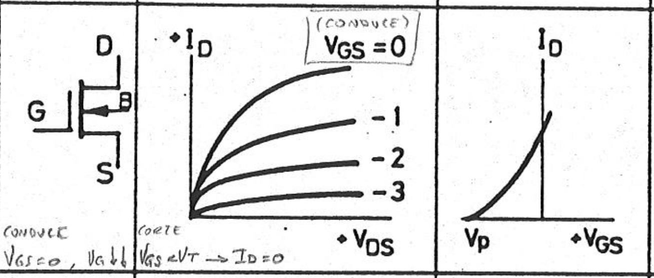
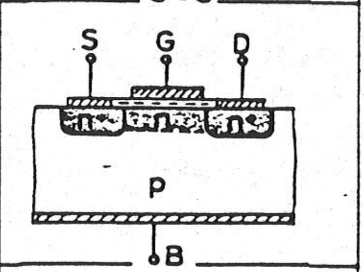
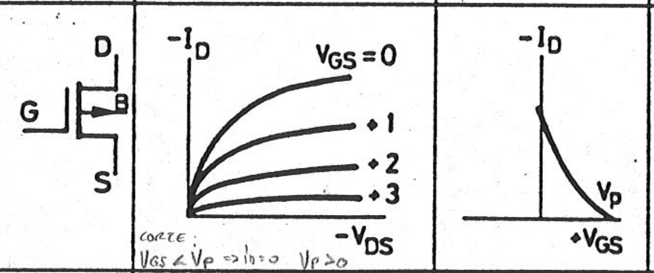
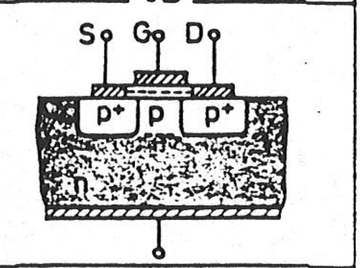
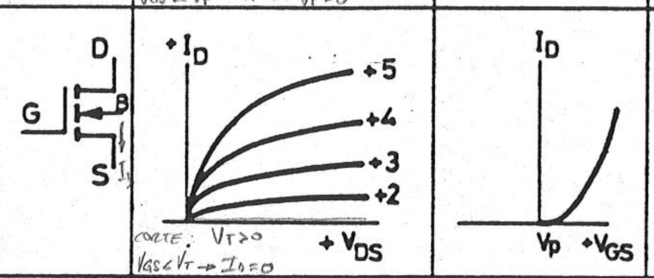
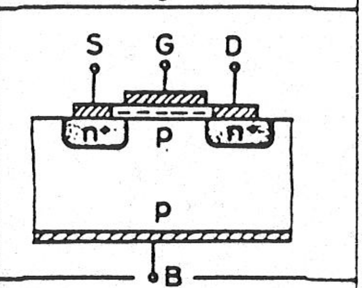
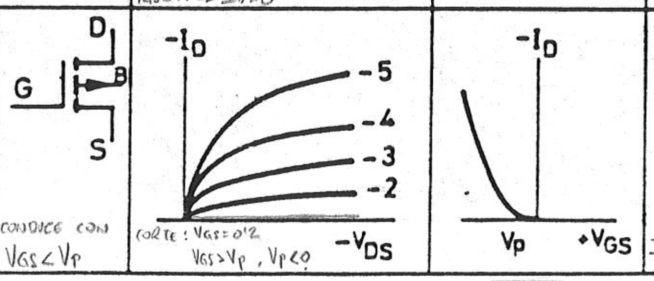
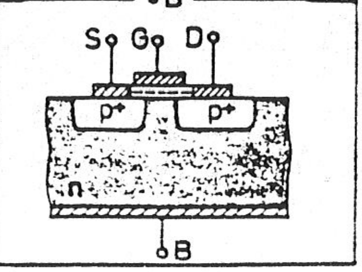
	EC	CC (Seguidor de emisor)	BC
Ganancia	$A_i \approx -h_{fe}$	$A_v \approx 1$	$A_i \approx -h_{fb} = \frac{h_{fe}}{1+h_{fe}}$
Impedancia de entrada	$h_{ie} = \frac{25 \cdot 10^{-3} h_{fe}}{I_{EQ}}$	$Z_i = h_{ie} + (h_{fe}+1) R_E$	$h_{ib} = \frac{h_{ie}}{1+h_{fe}}$
Impedancia de salida	$\frac{1}{h_{oe}} > 10^4 \Omega$	$Z_o \approx h_{ib} + \frac{r_i'}{h_{fe}+1}$	$\frac{1}{h_{ob}} = \frac{1+h_{fe}}{h_{oe}}$
Circuito equivalente + sencillo.			

Parametros híbridos h :

RESUMEN DE TRANSISTORES UNIPOLARES

$I_D = I_S$

$V_D > V_S$

TIPO			SIMBOLO / CARACTERISTICAS DE DRENADOR / CARACTERIST. de TRANSFERENCIA	V_p	CONSTRUCCION
FET de UNION . JFET	DEPLEXION	CANAL N		<0 $I_{DSS}>0$	
		CANAL P		>0 $I_{DSS}<0$	
MOS — FET de PUERTA AISLADA . MOST IGFET.	DEPLEXION (vaciamiento)	CANAL N		V_T <0 $I_{DSS}>0$	
		CANAL P		>0 $I_{DSS}<0$	
	ACUMULACION (NO CONDUCE $V_{GS}=0$)	CANAL N		≥ 0 $I_{DSS}>0$	
		CANAL P		≤ 0 $I_{DSS}<0$	

CANAL N : Sat $\Leftrightarrow V_{DS} \geq V_{GS} - V_p$ y $V_{GS} > V_p$

CANAL P : Sat $\Leftrightarrow V_{DS} \leq V_{GS} - V_p$ y $V_{GS} < V_p$

NO HAY CORTE

SAT:

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2$$

$1 mm^2 = 0'01 cm^2$

$1 mm = 0'1 cm$

Asunto: Fecha: Página:

$q_e = 1'6 \cdot 10^{-19} C$

SC. EXTRINSEC ($N > P$) (TIPUS N) [ ]= cm^{-3} — e^-, h^+ (FORATS) — $T = 273°K$

SC. INTRINSEC (ELEMENT PUR)

1. LLEI ACCIÓ MASSES: $np = n_i^2(T)$ (TEMPERATURA)

2. CONDUCTIVITAT: $\sigma = q_e \cdot (\mu_p \cdot p + \mu_n \cdot n)$ — $1'6 \cdot 10^{-19} C$, $cm^2/V \cdot s$ — DENSITAT CORRENT $(\Omega cm)^{-1}$

[ ] e^-, h^+: $n = p = n_i(T)$ cm^{-3}

$\sigma = q_e \cdot n_i \cdot (\mu_p + \mu_n)$ — MOVILITAT h^+, e^- — CONDUCTIVITAT $(\Omega \cdot cm)^{-1}$

[ ] IMPURESES (DONADORES, ACEPTORES) cm^{-3}

3. $N_d + p = N_a + n$ cm^{-3} — LLEI NEUTRALITAT CÀRREGA (ACEPTOR, DONADOR)

$\rho = \frac{1}{\sigma}$ Ωcm (σ - CONDUCTIVITAT) — RESISTIVITAT

RESISTENCIA Ω: $R = \rho \frac{l}{S}$

$R = \frac{1}{\sigma} \cdot \frac{l}{S}$ (cm, cm^2)

$dR = \rho(x) \frac{dx}{A}$ (A - SECCIÓ)

1, 3: $n^2 - (N_d - N_a) \cdot n - n_i^2 = 0$

DOPAT DONADORS (e^-) — SIMOVILITATS DEL MATEIX ORDRE

• $n \gg p \rightarrow n \simeq N_d$ $\quad \sigma = q_e \cdot \mu_n \cdot N_d$ $\quad \sigma = \frac{1}{R} \cdot \frac{l}{S}$

$N_a = 0$ 1, 2: $n^2 - \frac{\sigma}{q_e \mu_n} \cdot n + \frac{\mu_p}{\mu_n} n_i^2 = 0$, $n \neq n_i$!

DOPAT ACEPTORS (h^+)

• $p \gg n \rightarrow p \simeq N_a$ $\quad \sigma = q_e \mu_p \cdot N_a$ $\quad \rightarrow n = \frac{n_i^2(T)}{p}$

$N_d = 0$ $\quad n \ll p$

A. $J_{dn} = q_e \cdot D_n \cdot \frac{dn(x)}{dx}$ ($D_n = V_T \cdot \mu_n$) — CORRENT DIFUSIÓ e^-

B. $J_{an_p} = q_e \cdot \mu_{n_p} \cdot n(x) \cdot E(x)$ (σ; $p(x)$) — CAMP ELECTRIC

$J_{dp} = -q_e \cdot D_p \cdot \frac{dp(x)}{dx}$ — DENSITAT CORRENT DIFUSIÓ h^+

$J_{an} + J_{dn} = 0$

$J_{an_p} = -J_{dn_p}$ — EQUILIBRI — EN ABSENCIA DE CAMP ELÈCTRIC EXTERIOR.

$V_1 - V_2 = V_T \cdot \ln \frac{n_1}{n_2}$ — DIFERENCIA DE POTENCIAL — si $n_1 < n_2 \rightarrow \ln \frac{n_1}{n_2} < 0 \rightarrow V_2 > V_1$

$V_T = \frac{D_{n_p}}{\mu_{n_p}} = \frac{KT}{q_e}$ — POT. EQUIVALENT TEMP. — CONSTANT DIFUSIÓ — RELACIÓ EINSTEIN

$V_0 = V_T \cdot \ln \frac{N_a \cdot N_d}{n_i^2}$ (25mV) — POTENCIAL CONTACTE

A, B: $E(x) = -V_T \cdot \frac{1}{n(x)} \cdot \frac{dn(x)}{dx}$

POT. CONTACTE →

μm $W_0 = \sqrt{\frac{2\varepsilon}{q_e}\left(\frac{1}{N_a} + \frac{1}{N_d}\right) \cdot (V_0 - V)}$ μm — AMPLADA ZCE — TENSIÓ INVERSA POLARITZACIÓ — UNIÓ P-N ABRUPTA POL. — $\varepsilon = \varepsilon_r \cdot \varepsilon_0$ F/cm

$W_0 = W_n + W_p$ — LONGITUDS DE LES PARTS DE ZCE (W_n; W_p)

$W_{n_p} = \frac{N_{a_d}}{N_a + N_d} \cdot W_0$? ($W_p$: X_p; W_n: X_n) — AMPLADA ZCE

$N_a < N_d$, $X_p < X_n \rightarrow W_0 \simeq (W_n)$

$(W_p \cdot N_a = W_n \cdot N_D)$

N_D si $N_A \gg N_D$

$J = \sigma \cdot E$ — LLEI OHM

$E_{max} = -\frac{2V_0}{W_0}$ — CAMP MAXIM — ZONA SENSE POLARITZAR

$V = R \cdot I$ $\quad E = -\frac{dV}{dx} \rightarrow \int_0^x dV = -\int_0^x E dx \rightarrow V(x) - V(0) = -\int_0^x E dx$ ($V(0) = 0$)

$|E_m| = \sqrt{\frac{2 q_e}{\varepsilon} \frac{1}{\frac{1}{N_A} + \frac{1}{N_D}} (V_0 - V)}$

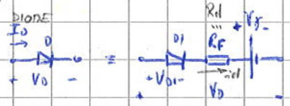
A $I_s = q_e A n_i^2 \cdot \left(\frac{D_p}{L_p} \cdot \frac{1}{N_d} + \frac{D_n}{L_n} \frac{1}{N_a}\right)$ — AREA CONTACTE — CORRENT INVERS SATURACIÓ — $P_n = \frac{n_i^2}{N_d}$, n_p

$L_{p_n} = \sqrt{D_{p_n} \tau_{p_n}}$ cm — ZONES NEUTRES — LONGITUD DE DIFUSIÓ — $\frac{D_p}{L_p} = \sqrt{\frac{D_p}{\tau_p}}$

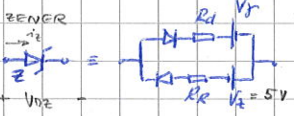
$L_{p_n} = X_{p_n} - W_{p_n}$ μm

$R_p = \frac{1}{\sigma} \cdot \frac{L_p}{A}$

$C_T = A \cdot \frac{\varepsilon}{W}$ F — CAPACITAT TRANSICIÓ



ON $\begin{cases} i_d > 0 \\ V_d = 0 \end{cases}$ OFF $\begin{cases} i_d = 0 \\ V_d < 0 \end{cases}$ IDEALS ($V_\gamma = 0$, $R_F = 0$)



INV $\begin{cases} i_d < 0 \\ V_d = -5V \end{cases}$ ($-V_z$) OFF $\begin{cases} i_d = 0 \\ -5 < V_d < 0 \end{cases}$

TENSIÓ ENTRADA: $V_i = V_{ef} \cdot \sqrt{2} \sin wt$ ($V_{max} = V_{PIC}$)

VALOR MITJÀ SENYAL PERIÒDIC (INTENSITAT): $I_{dc} = \frac{1}{T} \int_0^T I_{max} \sin(wt) dwt$ (PERIODE; I_{PIC})

VALOR EFICAÇ: $I_{Def} = \sqrt{\frac{1}{T} \int_0^T i_D^2 dwt} = \frac{I_{Dmax}}{\sqrt{2}}$ ($i = I_{max} \cdot \sin(wt)$)

POTENCIA MITJA DIODE: $P = \frac{1}{2\pi} \int_0^{2\pi} V_\gamma \cdot i \, dwt$ — FONT - $V_\gamma \cdot i$ — $\begin{cases} V_i = V_{max} \sin wt \\ i = i_{max} \sin wt \end{cases}$

$P_{MAX} = V \cdot I_{max}$

CORRENT DIODE MÀXIMA: $I_{D_{PIC}} \simeq I_m = V_m \sqrt{\frac{1}{R_L^2} + C^2 w^2}$

POTENCIA: $P_{MEDIA} = V_\gamma \cdot I_D$ (0'7V)

MITJA ONA: $I_D = I_{ODC} = \frac{V_{ODC}}{R_L}$

ONA COMPLETA, GRAETZ: $I_D = \frac{I_{ODC}}{2} = \frac{V_{ODC}}{2R_L}$

TENSIÓ INVERSA MÀXIMA: $V_{INV} = 2V_{im}$ $= V_{im}$ (GRAETZ)

MITJA ONA: $I_{DC} = \frac{I_{max}}{\pi}$ $\quad I_{ef} = \frac{I_{max}}{2}$ $\quad \frac{V_{max}}{\sqrt{2}} = V_{ef}$ $\quad P = \frac{V_{max} \cdot I_{max}}{4}$

- COND - MITJA ONA: $V_{OEFF} = \frac{V_m}{2}$ — ONA COMPLETA: $V_{OEFF} = \frac{V_m}{\sqrt{2}}$

ONA COMPLETA: $V_{O_{DC}} = \frac{2V_{om}}{\pi}$ (V_o MITJÀ) $\quad R_L = \frac{V_{odc}}{I_{odc}}$ ($V_{om} = I_{om} \cdot R_L$) $\quad I_{oef} = \frac{I_{om}}{\sqrt{2}}$ (màx) $\quad V_{oef} = \frac{V_{om}}{\sqrt{2}}$

$V_o = |V_i| = V_{im} |\sin wt|$ $\quad W = 2\pi \nu$ $\quad T = \frac{2\pi}{W}$ $\quad T = \frac{1}{\nu}$

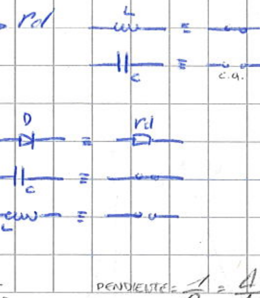
ARRISSAMENT DE TENSIÓ (MITJA ONA): $\Delta V_o = \frac{V_m}{\nu \cdot R_L \cdot C} = \frac{I_{odc} \cdot V_m}{V_{odc} \cdot C \cdot \nu}$ · $\frac{1}{2}$ (ONA COMPLETA → $2 \cdot R_L \cdot C \cdot \nu$) — FILTRE AMB CONDENSADOR

ONA COMPLETA — TENSIÓ PIC (SORTIDA): $V_{odc} = V_{im} - \frac{\Delta V_o}{2}$ — VALOR MITJÀ TENSIÓ SORTIDA

$\tau = R_L \cdot C$ $\quad \varphi = arctg(R_L \cdot C \cdot w) \simeq 90°$ $\quad \frac{dV_o(t)}{dt} = \frac{V_{co}}{R_L \cdot C}$

1. DC: $\frac{I_{DQ}}{V_{DQ}} \rightarrow r_d$

2. AC: $\frac{i_d}{V_d}$



$I_{DQ} = I_s \left(e^{\frac{V_{DQ}}{\eta V_T}} - 1\right)$

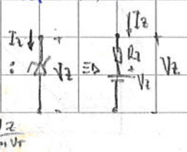
$r_d = \frac{\eta \cdot V_T}{I_{DQ}} = \frac{1}{\frac{di_D}{dv_D}|_Q} \cdot \frac{1}{m}$ $\quad \eta = 1$ (1'5) $\quad V_T = 25mV$

$\begin{cases} i_D = I_{DQ} + i_d \text{ (mA)} \\ V_D = V_{DQ} + v_d \text{ (V)} \end{cases}$

$r_d = \frac{V_d}{i_d}$

$V_A < V_B \rightarrow$ OFF

ZENER RUPTURA:



$V_i = I_z R_z + V_z$

PEND = $\frac{1}{R}$ — RESIST. VISTA PER DIODO EN AC O EN DC.

PENDIENTE = $\frac{1}{R} = \frac{\Delta I}{\Delta V}$

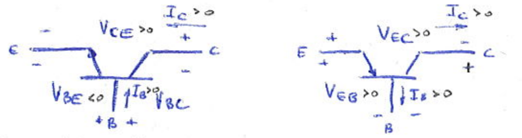
PEND. AC ≠ PENDIENTE DC.

- ZENER -
$V_z > 0$, $i_z = I_s e^{\frac{V_z}{\eta V_T}}$
NO COND $-V_z \le V_z < 0$
INVERSA $V_z < -V_z$

$m = \frac{1}{R_z}$

$I_{z(min)} = \frac{V_i(min) - V_z(min)}{R(max)} - \frac{V_z(min)}{R_L(min)}$

$I_{zmin} \le I_z \le I_{zmin}$ $\quad I_{Zmax} \leftrightarrow V_i(max)$, I_L min



$V_{CE}=V_{CB}+V_{BE}$

$I_E=I_B+I_C$ $\quad I_C=\alpha\cdot I_E+I_{CBO}$ $\quad V_{BE\,ACT}=0'7V$ $\quad I_B=(1-\alpha)I_E$ $\quad \boxed{I_C=\beta I_B}+(\beta+1)I_{CBO}$ $\quad \boxed{I_E=(1+\beta)I_B}$

h_{FE} ... ACTIVA

1° $I_{BQ}>0$ → ACTIVA o SAT. (NPN) $\quad I_{BQ}>0$ (PNP)

2° $V_{CEQ}>V_{CESAT}$ → ACTIVA ($V_{CESAT}=0'2V$) $\quad V_{CEQ}>V_{CESAT}$

$V_{CEQ}<0 \Rightarrow$ SAT. $\quad I_{CQ}>\beta I_{BQ} \Rightarrow$ SAT

. TRT EN SAT: $I_C>I_{C(SAT)}$ $\quad V_{CE}=0'2V$ $\quad I_{C(SAT)}=\frac{V_{CC}}{R_C}$

$V_{BE}>0$ DIRECTA, $V_{BC}>0$ DIRECTA.

. TRT EN ACTIVA: $V_{BE}>0$ DIRECTA, $V_{BC}<$ INVERSA

. TRT EN CORTE $I_B<0$.

$V_i<V_{BE} \Rightarrow$ CORTE

DC: condensador = circuit obert ; font = curtcircuit ; bobina = curtcircuit

AC: condensador = curtcircuit ; font = curtcircuit ; bobina = circuit obert

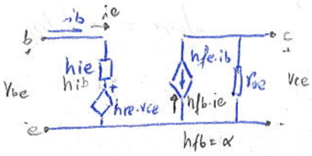
$h_{ie}=\frac{\eta V_T}{I_{BQ}}$

$v_{be}=h_{ie}\cdot i_b+h_{re}\cdot v_{ce}$

$i_c=h_{fe}\cdot i_b+h_{oe}\cdot v_{ce}$

$h_{ie}=\frac{\partial V_{BE}}{\partial i_B}\Big|_Q$ $\quad h_{re}=\frac{\partial V_{BE}}{\partial V_{CE}}\Big|_Q$

$h_{fe}=\frac{\partial i_C}{\partial i_B}\Big|_Q$ $\quad h_{oe}=\frac{\partial i_C}{\partial V_{CE}}\Big|_Q$



$h_{ie}=\frac{V_T}{I_{BQ}}$ $\quad h_{fb}=\alpha$ $\quad h_{fe}=\beta$

$h_{ib}=\frac{h_{ie}}{h_{ie}+1}$ $\quad h_{fb}=\frac{h_{fe}}{h_{fe}+1}$ $\quad h_{ob}=\frac{h_{oe}}{h_{fe}+1}$ $\quad r_{ob}=\frac{1}{h_{ob}}$ $\quad r_{oe}=\frac{1}{h_{oe}}$

GUANY TENSIÓ $A_V=\frac{\Delta V_o}{\Delta V_i}=\frac{\partial v_o}{\partial v_i}$ $\quad$ GUANY CORRENT $A_i=\frac{i_o}{i_i}$, $A_i=A_V\cdot\frac{Z_i}{R_L}$

$A_{V_i}=\frac{\Delta V_o\,(\text{MES})}{AV}$ (AMPLITUT MÀXIMA DEL SENYAL) $\quad Z_i=\frac{V_i}{i_i}$ $\quad Z_o=\frac{V_o}{i_o}$

R.C.C. – $I_C(V_{CE})$ $\quad$ R.C.A – $i_c(v_{ce})$ $\quad V_{CE}=V_{CEQ}+v_{ce}$

$i_C=I_{CQ}+i_c$

MARGES DINÀMICS TENSIÓ

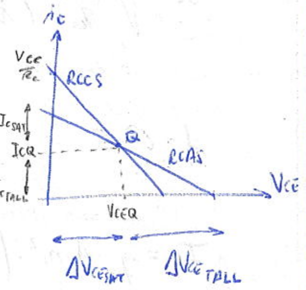
$\Delta V_{CE\,TALL}=V_{CE\,TALL}-V_{CEQ}$

$\Delta V_{CE\,SAT}=V_{CEQ}-V_{CESAT}$

MARGES DINÀMICS CORRENT

$\Delta I_{C\,TALL}=I_{CQ}-I_{C\,TALL}$

$\Delta I_{C\,SAT}=I_{CSAT}-I_{CQ}$



PNP

– V_{BE} – $\quad V_\gamma=-0'5$ $\quad$ – V_{CE} – SAT = –0'2

$V_{BE}=-V_{EB}$ $\quad$ ACT = –0'7

$V_{EB}=V_E-V_B$ $\quad$ SAT = –0'8

TALL = 0

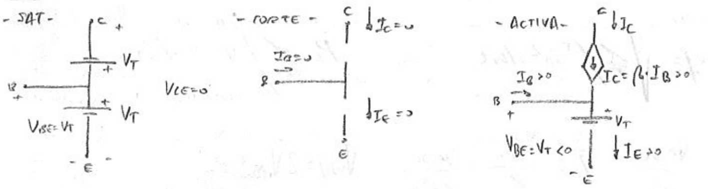
–ZONES FUNCIONAMIENTO–

CORTE: $V_{BB}<V_{BE\,ACT}=0'7V$, $I_{BQ}<0$

SAT: $V_{CESAT}=0'2V$, $I_C<\beta I_B$, $I_{BQ}>0$ $\quad V_{BE}=V_{BE\,ACT}$

ACT: $V_{CEQ}>V_{CESAT}$ $\quad I_{BQ}>0$.

NPN



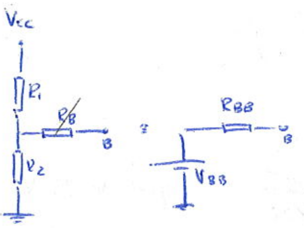
BJT: CORTE: $I_B=0$ $\quad I_C=0$ $\quad V_{BE}<V_{BEACT}$

ACT: $V_{BE}=V_{BEACT}$ $\quad I_C=h_{FE}\cdot I_B$ $\quad I_B>0$ $\quad V_{CE}>V_{CESAT}$

SAT: $V_{BE}=V_{BEACT}$ $\quad I_C=I_{CSAT}$ $\quad V_{CE}=V_{CESAT}$ $\quad I_B>0$

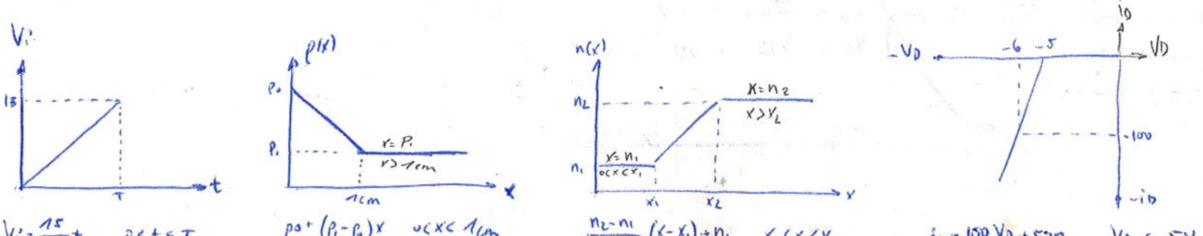
$h_{FE}\cdot I_B>I_{CSAT}$

PUNTO Q BJT: i_B V_{BE} (RCE) $\quad i_C$ V_{CE} (RCS)

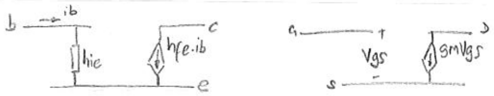


$R_{BB}=\frac{R_1 R_2}{R_1+R_2}+R_B$

$V_{BB}=\frac{R_2}{R_1+R_2}\cdot V_{CC}$



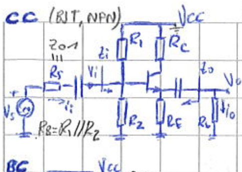
$V_i=\frac{15}{T}t$ $\quad 0\leq t\leq T$ $\qquad \rho_0+(\rho_1-\rho_0)x$ $\quad 0<x<1cm$ $\qquad \frac{n_2-n_1}{x_2-x_1}(x-x_1)+n_1$ $\quad x_1\leq x\leq x_2$ $\qquad i_D=100V_D+500$ $\quad V_D<-5V$



Fecha: $R_L=\infty$ C.A.

Asunto: Página:

CC (BJT, NPN)



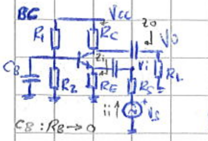
$V_i = i_b h_{ie} + V_o \rightarrow V_o < V_i \rightarrow A_V < 1$, $A_V > 0$ (EN FASE) NORMALMENTE $h_{ie} \ll (h_{fe}+1)(R_E \parallel R_L) \rightarrow A_V \approx 1$ SEGUIDOR TENSIÓN

$A_V = \dfrac{(h_{fe}+1)(R_E \parallel R_L)}{h_{ie}+(h_{fe}+1)(R_E \parallel R_L)}$ $A_i = \dfrac{(h_{fe}+1) R_B}{R_B + h_{ie} + (h_{fe}+1)(R_E \parallel R_L)} \cdot \dfrac{R_E}{R_E+R_L}$ $Z_i = R_B \parallel \left[h_{ie}+(h_{fe}+1)(R_E \parallel R_L)\right]$ $Z_o = R_E \parallel \left[\dfrac{R_S \parallel R_B + h_{ie}}{h_{fe}+1}\right]$ (Z_{o1} (MULTIETAPA))

$R_B = R_1 \parallel R_2$

$V_o = (h_{fe}+1) i_b (R_E \parallel R_L)$ $V_i = i_b \left[h_{ie} + (h_{fe}+1)(R_E \parallel R_L)\right]$ $i_o = \dfrac{V_o}{R_L}$ $i_i = \dfrac{V_i}{R_B} + i_b = \dfrac{V_i}{[\dots]}$ $i_o = \dfrac{V_o}{R_E} + (h_{fe}+1) i_b$ $i_b = \dfrac{V_o}{h_{ie} + R_S \parallel R_B}$

BC



Z_{i2} (MULTIETAPA)

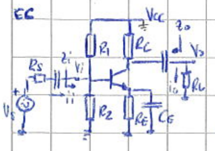
$A_V = \dfrac{h_{fe}(R_C \parallel R_L)}{h_{ie}+R_B}$ $A_i = \dfrac{h_{fe}}{h_{fe}+1} \cdot \dfrac{R_C}{R_C+R_L} \cdot \dfrac{1}{1+\dfrac{h_{ie}+R_B}{(h_{fe}+1)R_E}}$ $Z_i = R_E \parallel \left[\dfrac{R_B+h_{ie}}{h_{fe}+1}\right]$ $Z_o = R_C$ $Z_o = R_C \parallel Z_o' \cdot$ SUPERFLUA $Z_i = Z_i' \parallel R_C$ $Z_i' = \dfrac{-i_b(R_B+h_{ie})}{-i_b(1+h_{fe})} = \dfrac{V_i}{i_i'}\Big|_{i_{RE}=0}$

$A_V > 0$, $A_V \uparrow$ MEDIANTE C_B, $R_B \rightarrow 0$ i_{RE} $-h_{fe} i_b - i_b$

$C_B : R_B \rightarrow 0$

$V_o = -h_{fe} \cdot i_b (R_C \parallel R_L)$ $V_i = V_{RE} = V_{hie} + V_{RB} = -i_b(R_B + h_{ie})$ $i_o = -h_{fe} \cdot i_b \dfrac{R_C}{R_C+R_L}$ $i_i = \dfrac{V_i}{R_E} - (h_{fe}+1) i_b = -i_b \left[\dfrac{R_B + h_{ie}}{R_E} + h_{fe}+1\right]$

EC



$A_V = -\dfrac{h_{fe}(R_C \parallel R_L)}{h_{ie}+(h_{fe}+1)R_E}$ $A_i = \dfrac{-h_{fe} \cdot R_B}{R_B + h_{ie} + (h_{fe}+1)R_E} \cdot \dfrac{R_C}{R_C+R_L}$ $Z_i = R_B \parallel \left[h_{ie} + R_E(h_{fe}+1)\right]$ $Z_o = R_C$ ($i_b = 0 \rightarrow h_{fe} \cdot i_b = 0$)

$C_E \rightarrow R_E = 0$

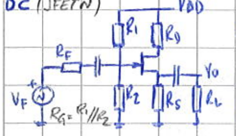
$V_o = -i_b h_{fe}(R_C \parallel R_L)$ $V_i = i_b \left[h_{ie} + (h_{fe}+1) R_E\right]$ $i_o = \dfrac{V_o}{R_L}$ $i_i = \dfrac{V_i}{R_B} + i_b$ $V_i : i_b = \dfrac{V_i}{[\dots]}$

MODELO CON h_{re} Y r_{oe}

$V_o = -h_{fe} \cdot i_b \cdot (r_{oe} \parallel R_C \parallel R_L)$ $V_i = i_b \cdot h_{ie} - h_{re} \cdot h_{fe} \cdot i_b (r_{oe} \parallel R_C \parallel R_L)$ $i_i = \dfrac{V_i}{R_B} + i_b$ $Z_o = \dfrac{V_P}{i_P}$ $i_P = V_P \left(\dfrac{1}{r_{oe} \parallel R_C} + \dfrac{h_{fe} \cdot h_{re}}{R_S \parallel R_B + h_{ie}}\right)$

$A_V = \dfrac{-h_{fe}(r_{oe} \parallel R_C \parallel R_L)}{h_{ie} - h_{re} \cdot h_{fe}(r_{oe} \parallel R_C \parallel R_L)}$ $Z_i = R_B \parallel \left[h_{ie} - h_{fe}(r_{oe} \parallel R_C \parallel R_L)\right]$ $A_i = A_V \cdot \dfrac{Z_i}{R_L}$ $Z_o = r_{oe} \parallel R_C$ $A \gg B$

DC (JFET N)



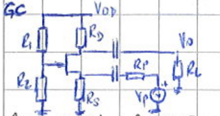
$A_V = \dfrac{g_m(R_S \parallel R_L)}{1+g_m(R_S \parallel R_L)}$ $A_i = \dfrac{g_m}{1+g_m(R_S \parallel R_L)} \cdot \dfrac{R_S \cdot R_G}{R_S+R_L}$ $Z_i = R_G$ $Z_o = R_S \parallel \dfrac{1}{g_m}$ ← $i_o = \dfrac{V_o}{R_S} - g_m V_{gs}$ $V_o = -V_{gs}$

$V_i > V_o \rightarrow A_V < 1$, $A_V > 0$ NO INV. FASE

$R_G = R_1 \parallel R_2$

$V_o = g_m V_{gs}(R_S \parallel R_L)$ $V_i = V_g = V_{gs} + V_o = V_{gs}\left[1+g_m(R_S \parallel R_L)\right]$ $i_o = g_m V_{gs} \dfrac{R_S}{R_S+R_L}$ $i_i = \dfrac{V_i}{R_G} = \dfrac{V_{gs}(1+g_m(R_S \parallel R_L))}{R_G}$

GC



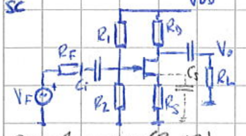
$A_V = g_m(R_D \parallel R_L)$ $A_i = \dfrac{g_m R_S}{1+g_m R_S} \cdot \dfrac{R_D}{R_D+R_L}$ $Z_i = R_S \parallel \dfrac{1}{g_m}$ $V_{gs} = -V_i$ $Z_o = R_D$ ($Z_o = R_D \parallel Z_o'$) KCL$_S$: $g_m V_{gs} = \dfrac{V_S}{R_S \parallel R_F}$; $V_S = -V_{gs} \rightarrow V_{gs} = 0 \rightarrow i_g = 0 \rightarrow Z_o' = \infty$

$i_{RS} = 0 \rightarrow V_{gs} = 0$

$A_V > 0$, SI $R_L \downarrow \rightarrow A_V$ PEQUEÑA

$V_o = -g_m V_{gs}(R_D \parallel R_L)$ $V_i = V_S = -V_{gs}$ $i_o = -g_m V_{gs} \dfrac{R_D}{R_D+R_L}$ $i_i = \dfrac{V_i}{R_S} - g_m V_{gs} = -V_{gs}\left(\dfrac{1}{R_S} + g_m\right)$

SC

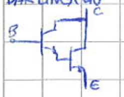


$A_V = \dfrac{-g_m(R_D \parallel R_L)}{1+g_m R_S}$ $A_i = \dfrac{-g_m}{1+g_m R_S} \cdot \dfrac{R_D R_G}{R_D+R_L}$ $Z_i = R_G$ $i_i = \dfrac{V_i}{R_G}$ $Z_o = R_D$ $A_V < 0 \rightarrow$ INVERSIÓN DE FASE

$V_o = -g_m V_{gs}(R_D \parallel R_L)$ $V_i = V_{gs} + V_{RS} = V_{gs} + g_m V_{gs} R_S$ $i_o = \dfrac{V_o}{R_L} = -g_m V_{gs} \dfrac{R_D}{R_D+R_L}$ $i_i = \dfrac{V_i}{R_G}$

$C_S \rightarrow A_{V_{MAX}} = -g_m(R_D \parallel R_L) \rightarrow A_{i_{MAX}} = -g_m \dfrac{R_D R_G}{R_D+R_L}$ $A_{V_{MAX}} = -g_m R_D \parallel R_L \rightarrow$ SIN R_L $A_V = -g_m R_D$

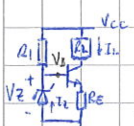
- **DARLINGTON** EN DC:



$h_{FE} = \dfrac{I_C}{I_B} = h_{FE1} \cdot h_{FE2}$ $V_{BE} = 1.4V$ $V_{CESAT} = V_{CE2SAT} + V_{CE1SAT} = 0'9V \rightarrow$ T2 NUNCA EN SAT.

$V_{CE} = V_{CE1} + V_{BE2}$ EN AC: $h_{fe} = \dfrac{i_c}{i_b} = h_{fe1} \cdot h_{fe2}$ $h_{ie} = \dfrac{v_{be}}{i_b}\Big|_{v_{ce}=0} = 2 h_{ie1}$ $h_{ie2} = \dfrac{V_T}{I_{BQ2}} = \dfrac{h_{ie1}}{h_{FE1}+1}$ $I_{BQ2} = I_{BQ1}(h_{FE1}+1)$

- **FUENTES DE CORRIENTE**

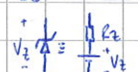


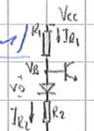
$V_Z < V_{CC}$ V_B

$I_L \approx I_E = \dfrac{V_Z - V_{BEACT}}{R_E}$ $Z_o = \dfrac{(r_{oe}+R_E)(h_{ie}+R_B) + r_{oe} \cdot R_E(h_{fe}+1)}{h_{ie}+R_E+R_B}$

$I_{B} \ll I_{R1}$

$I_Z = I_{R1} = \dfrac{V_{CC}-V_Z}{R_1} - I_B$ (DESPRECIABLE)

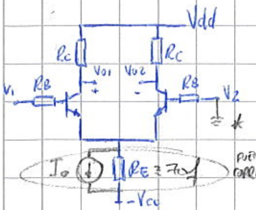




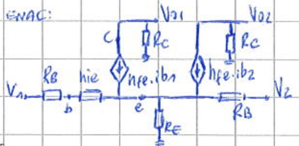
$I_L \approx I_E = \dfrac{V_B - V_{BEACT}}{R_E}$ $V_B = V_D + I_{R2} \cdot R_2$

$I_{R1} = I_{R2} = \dfrac{V_{CC}-V_D}{R_1+R_2}$ $I_E = \dfrac{V_{RE}}{R_E}$ $V_{BEACT} = V_B - V_E$

- **DIFERENCIAL BIPOLAR SIMÉTRICO**



EN AC:



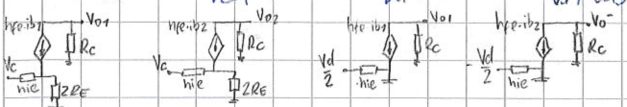
$V_{o1} = A_{d1} \cdot V_d + A_{c1} \cdot V_c$
$V_{o2} = A_{d2} V_d + A_{c2} \cdot V_c$

$A_{c1} = \dfrac{-h_{fe} \cdot R_C}{R_B + h_{ie} + 2R_E(h_{fe}+1)}$ $A_{c2} = \dfrac{-h_{fe} \cdot R_C}{R_B + h_{ie} + 2R_E(h_{fe}+1)}$

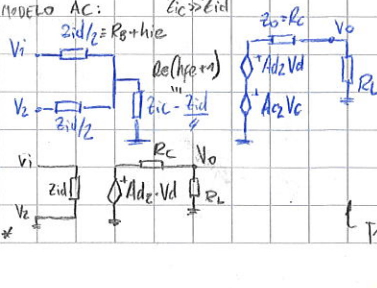
$A_{d1} = \dfrac{-h_{fe} R_C}{2(R_B+h_{ie})}$ $A_{d2} = \dfrac{+h_{fe} R_C}{2(R_B+h_{ie})}$

$V_o = V_{o1} - V_{o2} = (A_{c1} - A_{c2}) V_c + (A_{d1} - A_{d2}) V_d$

$A_{c1} = \dfrac{V_{o1}}{V_c}\Big|_{V_d=0}$ $A_{c2} = \dfrac{V_{o2}}{V_c}\Big|_{V_d=0}$ $A_{d1} = \dfrac{V_{o1}}{V_d}\Big|_{V_c=0}$ $A_{d2} = \dfrac{V_{o2}}{V_d}\Big|_{V_c=0}$ $A_c = \dfrac{V_o}{V_c}\Big|_{V_d=0}$ $A_d = \dfrac{V_o}{V_d}\Big|_{V_c=0}$



MODELO AC: $Z_{ic} \gg Z_{id}$



$r_{oe} = \infty$:

$CMRR = \left|\dfrac{A_d}{A_c}\right|$ $Z_{o1} = Z_{o2} = R_C$ $Z_{id} = 2(h_{ie}+R_B)$ $Z_{ic} = \dfrac{R_B + h_{ie}}{2} + R_E(h_{fe}+1)$ T1 = T2 $R_{B1} = R_{B2} = 0$

ASIMÉTRICA:

$CMRR = \dfrac{1}{2} + \dfrac{R_E(h_{fe}+1)}{R_B + h_{ie}} = \dfrac{A_{d1}}{A_{c1}} = \dfrac{A_{d2}}{A_{c2}}$

$A_d = A_{d2} \cdot \dfrac{R_L}{R_C+R_L} = \dfrac{h_{fe}(R_C \parallel R_L)}{2 h_{ie}}$

$A_c = A_{c2} \cdot \dfrac{R_L}{R_C+R_L} = \dfrac{-h_{fe}(R_C \parallel R_L)}{h_{ie} + 2 R_E \dots}$

$R_B = 0$, $Z_d = R_E$

JFETN:

$I_D > 0 \rightarrow I_{DSS} > 0$

$V_{GS} < 0 \rightarrow V_p < 0$

EN SAT: $V_{GS} < 0$ $\quad V_{GS} > V_p$ $\quad V_{DS} \geq V_{GS} - V_p$

JFETP:

$I_D \leq 0 \rightarrow I_{DSS} < 0$

$V_{GS} \geq 0 \rightarrow V_p > 0$

EN SAT: $V_{DS} \leq V_{GS} - V_p$

PUNTO TRABAJO: V_{GSQ} $\quad I_{DQ}$ $\quad V_{DSQ}$ $\qquad$ EN SAT: $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2$ $\qquad I_G \simeq 0 \equiv I_D = I_S$

PEQUEÑA SEÑAL: (EN SAT)

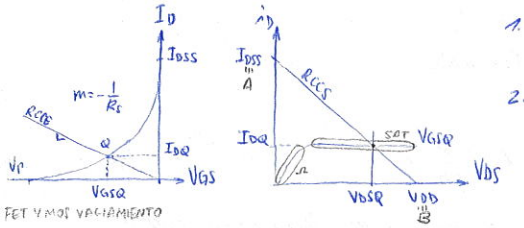
$i_g = Y_{is} \cdot V_{gs} + Y_{rs} \cdot V_{ds}$

$i_d = Y_{FS} \cdot V_{gs} + Y_{os} \cdot V_{ds}$

$Y_{is} = \frac{\partial i_G}{\partial V_{GS}}\Big|_Q$ $\quad Y_{rs} = \frac{\partial i_G}{\partial V_{DS}}\Big|_Q$ $\quad Y_{FS} = \frac{\partial i_D}{\partial V_{GS}}\Big|_Q$ $\quad Y_{os} = \frac{\partial i_D}{\partial V_{DS}}\Big|_Q$

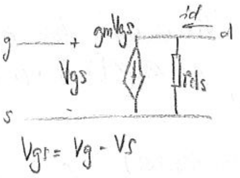
$Y_{12} \cdot V_{ds} = Y_{rs} \cdot V_{ds}$ $\quad Y_{21} \cdot V_{gs} = Y_{FS} \cdot V_{GS} = g_m \cdot V_{gs}$ $\quad r_{gs} = \frac{1}{Y_{11}} = \frac{1}{Y_{is}}$ $\quad r_{ds} = \frac{1}{Y_{22}} = \frac{1}{Y_{os}}$

TRANSCONDUCTANCIA: $g_M = Y_{FS} = g_{mo}\left(1 - \frac{V_{GSQ}}{V_p}\right)$ $\quad g_{mo} = -\frac{2 I_{DSS}}{V_p}$ $\quad g_m = g_{mo}\sqrt{\frac{I_{DQ}}{I_{DSS}}}$ $\quad g_m = \frac{\partial i_D}{\partial V_{GS}}\Big|_Q$



1. $V_{DD}/_{V_{DS}=0}$; $I_{DS}\big|_{V_{DS}=0} \equiv A$

2. $V_{DD}/_{I_D=0}$; $V_{DS}\big|_{I_D=0} \equiv B$



$V_{gs} = V_g - V_s$

$r_{ds} \rightarrow \infty \equiv$ C.A.

NMOS:

· I_D EN Ω: $I_D = \mu_n C_o \frac{W}{L}\left[(V_{GS} - V_p) V_{DS} - \frac{V_{DS}^2}{2}\right]$

· $V_{GD} \cong V_{GS} \rightarrow V_{GD} = V_{GS} + V_{SD} \simeq V_{GS}$ (with $V_{SD} = -V_{DS}$)

RESISTENCIA DEL CANAL: $I_D = \frac{V_{DS}}{R_{CANAL}}$

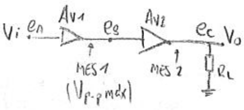
· I_D EN SAT: $I_D = \frac{\mu_n C_{ox}}{2} \cdot \frac{W}{L} \cdot (V_{GS} - V_p)^2$ $\qquad V_{DS} \geq V_{GS} - V_p$, $\quad V_{GS} > V_p$

- MULTIETAPA -

1. ANÁLISIS DC: Q EN CADA ETAPA $\quad I_{BQ1}$ $\; I_{CQ1}$ $\; V_{CEQ1}$, $\; I_{BQ2}$ $\; I_{CQ2}$ $\; V_{CEQ2}$

2. ANÁLISIS AC: Z_{i2} (sin Z_{o1}) A_{V2} ⟶ Z_{i1} (con Z_{i2}) A_{V1} $\qquad Z_{o1}$ (sin Z_{i2}) ⟶ Z_{o2} (con Z_{o1}) $\equiv R_S$ $\qquad$ CONJUNTO: $Z_i = Z_{i1}$ $\quad Z_o = Z_{o2}$ $\quad A_V = A_{V1} \cdot A_{V2}$ $\quad A_i = A_V \cdot \frac{Z_i}{R_L}$

3. MES EN CADA ETAPA: $\Delta V_{ce1\,SAT} = V_{CEQ1} - V_{CESAT}$; $\Delta V_{ce1\,TALL} = \frac{I_{CQ1}}{|\text{PEND. RCA}|}$; ΔV_{o1} ... MES V_{o1} = MES $V_{ce1} = 2 \times \min(\Delta V_{ce1\,SAT}, \Delta V_{ce1\,TALL})$ $\qquad$ ·IGUAL PARA ETAPA 2: $\Delta V_{o2} \equiv \Delta V_{ce2}$



A. $\frac{MES\,2}{|A_{V2}| \cdot |A_{V1}|}$ ⟵ $\frac{MES\,2}{|A_{V2}|}$ ⟵ 'MES 2' (MES (V_{o2}), $V_{p\text{-}p\,máx}$) $\qquad$ B. $\frac{MES\,1}{|A_{V1}|}$ ⟵ 'MES 1' (MES (V_{o1}), $V_{p\text{-}p\,máx}$) ⟶ MES 1 × $|A_{V2}|$

MES (V_o): 1. MES (V_{o1}) $< \frac{MES(V_{o2})}{|A_{V2}|}$ ⟶ MES (V_o) = MES (V_{o1}) · $|A_{V1}|$ $\qquad$ 2. MES (V_{o1}) $> \frac{MES(V_{o2})}{|A_{V2}|}$ ⟶ MES (V_o) = MES (V_{o2}).

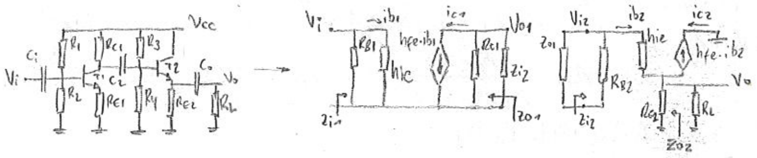
* MES MÁXIMA EN V_o (R_{C1}): MES (V_o)

1. MES (V_{o1}) > MES (V_{i2}) = $\frac{MES(V_{o2})}{|A_{V2}|} \equiv \Delta V_{o2}$

2. PUNTO Q (R_{C1}) (ETAPA 1) $\{V_{CEQ}(R_{C1})$, $I_{CQ}, I_{BQ}\}$

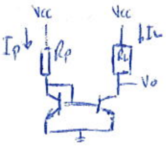
3. $\Delta V_{ce\,SAT} \geq \frac{MES(V_{i2})}{2}$ $\quad \Delta V_{ce\,TALL} \geq \frac{MES(V_{i2})}{2}$ ⟶ $\Delta V_{CESAT} = V_{CEQ} - V_{CESAT}$ (with $V_{CEQ}(R_{C1})$) ; $\Delta V_{CE\,TALL} = I_{CQ}(R_{C1} \,//\, Z_{i2})$

EJEMPLO: EC − CC $\qquad$ EN AC:



↳ × GLOBALMENTE: MES(V_o) (GLOBAL) = MES (V_{o2}) (ETAPA 2)

MÁXIMA ENTRADA: $\frac{MES(V_o)_{GLOBAL}}{|A_V|}$; $|A_V| = |A_{V1}| \cdot |A_{V2}|$ (con $R_L = Z_{i2}$)



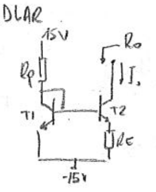
T1 SIEMPRE ACTIVA.

$V_{CE} = V_{BE} = 0'7V$

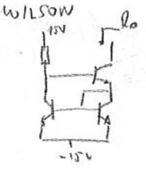
$I_{C1} = I_{C2} = I_{ES1} \cdot e^{\frac{V_{BE1}}{V_T}}$

$I_L = \frac{I_P}{1 + \frac{2}{h_{FE}}}$ $\qquad I_P = \frac{V_{RP}}{R_P} = \frac{V_{CC} - V_{BEACT}}{R_P}$

WIDLAR



$R_E = 0$: $\quad I_o = I_{ERA} + I_{ER2}$ $\quad I_{RP} = I_o$ $\quad R_P = \frac{15 - 0'7 - (-15)}{I_o}$

$R_o = h_{oe2} = \frac{V_A}{I_{CQ2}}$ ($I_{CQ2} = I_o$)

WILSON